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The Feasibility of Multiscale Modeling of Tunnel Fires Using FDS 6

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Introduction

CFD modeling of fires in long tunnels presents a computational challenge given by the large domains. The need for accurate results means that there is a high number of cells to be calculated, which increases the simulation time to unfeasible lengths for investigating multiple fire scenarios.

Multiscale modeling for tunnel fires is viewed as an efficient way to achieve accurate results while keeping the simulation time relatively short . It has been validated for RANS-based CFD software [1-3] and the present work aims to implement this method into FDS v.6, an open-source, fire-specific CFD software which uses Large Eddy simulations [4], compare the results with the reference works [1-3] and analyze its feasibility.

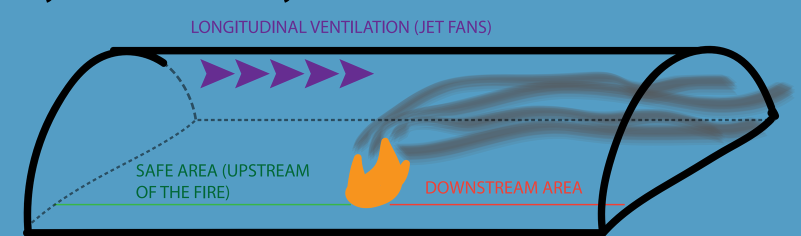


Fig. 1 Tunnel fire safety strategy: longitudinal ventilation, which aims at keeping the upstream area free of smoke

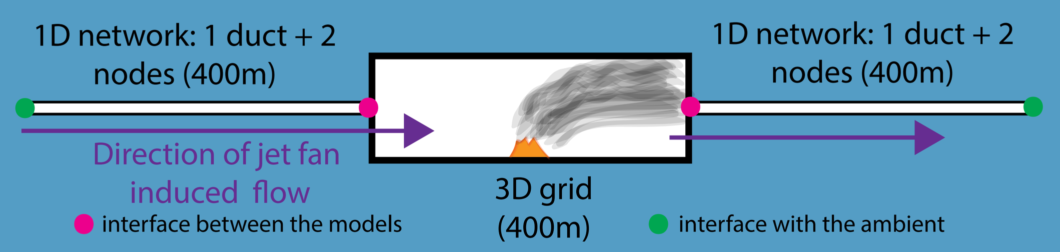


Fig. 2 The concept of multiscale modeling of tunnel fires using FDS 6

Research Questions

- Can multiscale modeling be implemented in FDS 6 using the new HVAC feature?
- How accurate are the results and how much time is saved?

Multiscale Modeling Implementation in FDS 6

3D Model

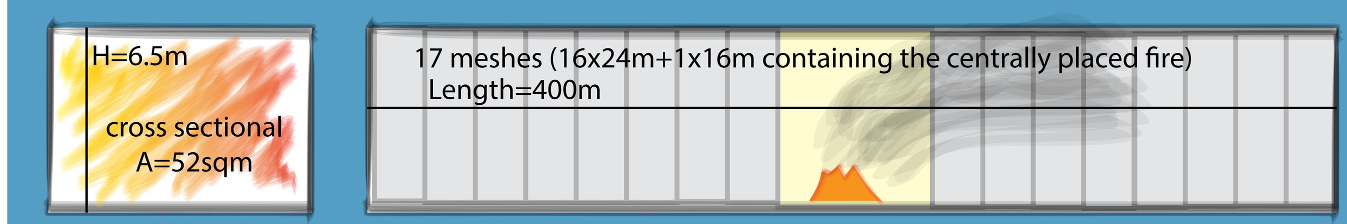


Fig. 3The geometry of the 3D model (not to scale)

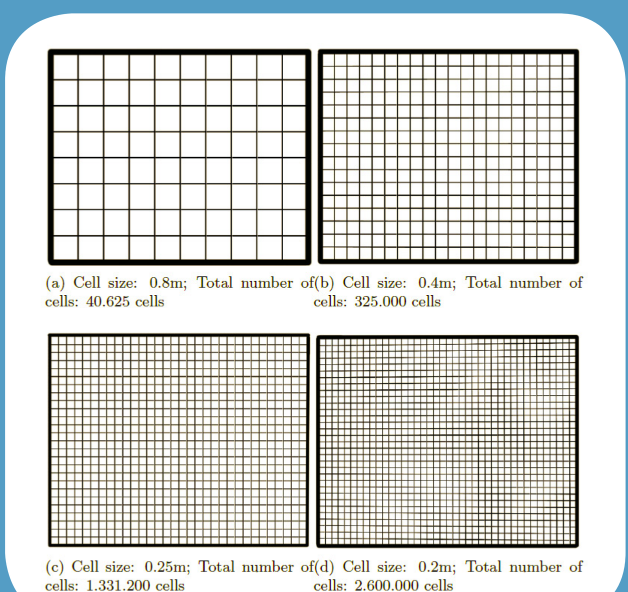
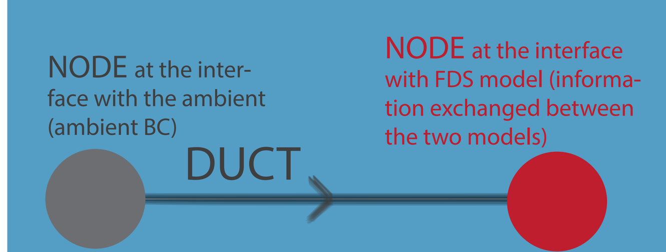


Fig. 4 Cross sections of the meshes for the grid sensitivity analysis

Multiple meshes
- induce a maximum difference of 14% in temperature and velocity results measured in certain points near the mesh interfaces
- speed up the calculation from 198h to around 3 hours (using from approx. 11 bil. FLOPS to approx 140 bil.-- FLOPS)

Fire scenario
- HRR of 30 MW (peak HRR of burning bus [5])
- simple chemical model
- duration of 600s

1D Model



- fixed flow equivalent to 3 jet fans
- absolute roughness determined according to the hydraulic diameter and relative roughness chosen from Moody's chart
- length of 400 m

Fig. 5 The upstream duct and node network

Coupling of the two models

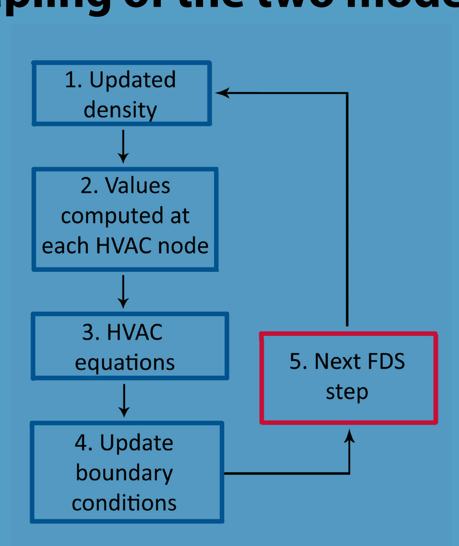


Fig. 6 The interaction between the models

Results and Discussion

Grid Sensitivity Analysis

The results given by FDS are highly dependent on the grid size. Reducing the grid size does not automatically mean more accuracy, but it does significantly increase the run time of the simulation. Therefore, it is important to find a balance between the desired result accuracy and keeping the simulation time at a level acceptable to the user.

For this, a grid sensitivity analysis was performed, using meshes with cell sizes of 0.8m, 0.4m, 0.25m and 0.2m. The results were analyzed 10m downstream of the fire (210m) and 100m downstream of the fire (300m). While the simulation time ranged from 92h to 0.8 hours from the smallest cell size to the largest one, the results accuracy did not improve significantly from 0.4 to 0.25-0.2m. Therefore, a cell size of 0.4m was chosen for the feasibility analysis.

Table 1. Comparison between the average results using dierent cell sizes

	0.2m	0.25m	0.4m	0.8m
Average temperature at 210m [°C]	126	128	124	152
Deviation	-	+2%	-1%	+21%
Average temperature at 300m [°C]	114	118	112	110
Deviation	-	+4%	-2%	-3%
Average velocity at 210m [m/s]	6.6	6.7	6.6	5.9
Deviation	-	+2%	+1%	-10%
Average velocity at 300m [m/s]	7.4	7.3	7.0	6.5
Deviation	-	0%	-6%	-12%

Table 2. Comparison between the runtimes using different cell sizes

	0.2m	0.25m	0.4m	0.8m
Runtime [h]	92	39	6	0.8

Feasibility Analysis

An important step to be performed after obtaining results in FDS is to validate them. The multiscale method adapted for FDS is compared to the one used in the steady state simulation done with the Fluent code. Longitudinal temperature and velocity slices passing through the center line are compared for one ventilation scenario, namely the one using 3 active jet fan pairs on the tunnel conditions.

The shapes of the velocity and temperature distribution are similar, with higher velocities in the FDS model given by the fixed flow that does not allow the flow interaction in the same way that the reference work allowed. However, it is important to keep in mind the differences between the modeling techniques used in this comparison. With that in mind, it is considered that multiscale modeling has been successfully implemented in FDS 6.

Table 3. Differences between modeling techniques employed by FDS and Fluent

	FDS	Fluent
DESCRIPTION	CFD model of fire-driven flow	General purpose CFD tool
FIRE	Dedicated combustion model	Volumetric heat source
MESH	Structured , rectangular	Unstructured
EQUATIONS	Low pass filter applied to Navier Stokes	Reynolds time-averaged Navier Stokes

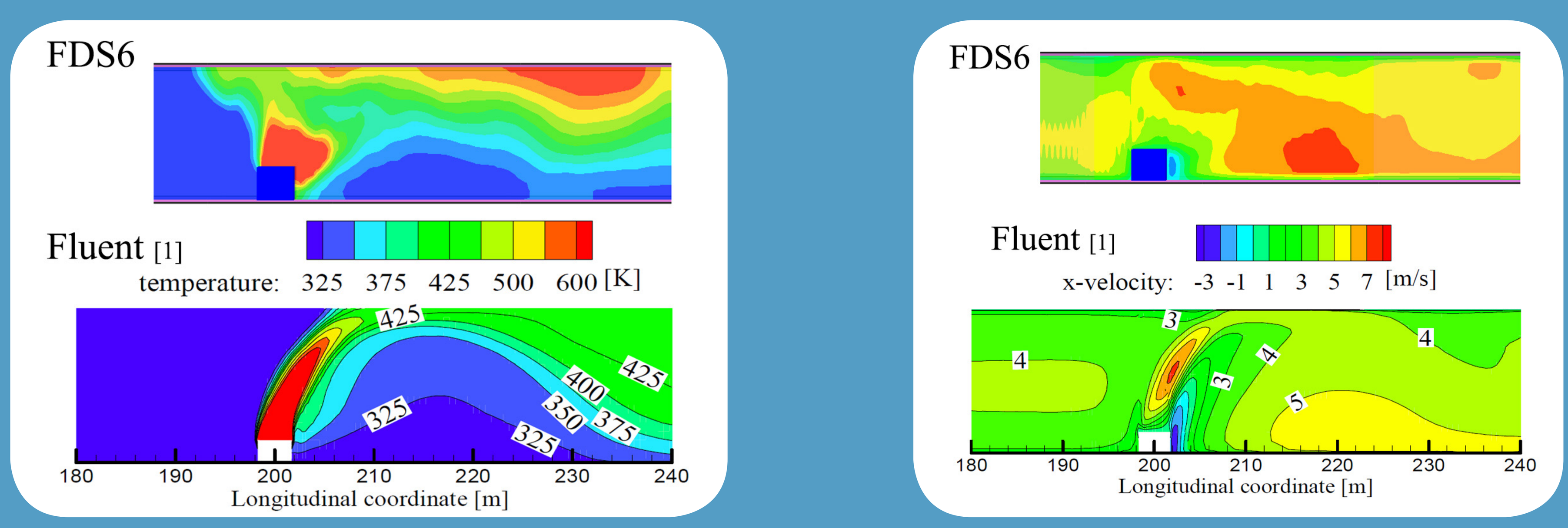


Fig. 7 Result comparison for temperature (left) and x-velocity (right) between the RANS steady state model from Fluent and the LES transient model from FDS with values averaged over a period of 20 seconds

Conclusion and Further Work

Answers to research questions:

- Yes, multiscale modeling can be implemented in FDS 6 using the new HVAC feature
- The results are similar to the full CFD solution (5% difference in mass flow results), while the time is significantly reduced (from a few weeks to a few hours)

FUTURE WORK:

- fixed flow to be changed to a quadratic flow in order to allow flow interactions between the 3D and 1D models
- simulating other ventilation scenarios, especially transverse ventilation to see how the method performs in that case
- improving the overall model (more compex chemical reaction, offset of the fire location)

About the presenting author

Izabella M. Vermesi worked on multiscale modeling of tunnel fires as part of her MSc thesis at the Technical University of Denmark, under the supervision of the other three authors. She obtained her MSc degree from DTU in 2013 and she has recently moved to London to start a PhD program entitled 'Computational Pyrolysis' at the Department of Mechanical Engineering of Imperial College under the supervision of Dr. Guillermo Rein.

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